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Trajectory Sensitivities for Sun-Mars Libration Point Missions

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Overview

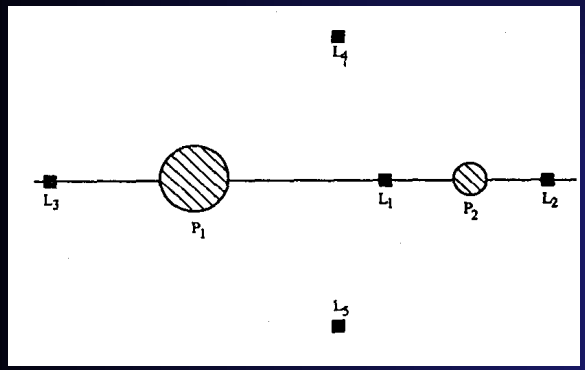
- Introduction
- Sun-Mars Libration Point Missions
- Mission Simulations and Analysis
- Targeting Methods using STK *Astrogator*
- Stationkeeping
- Conclusion

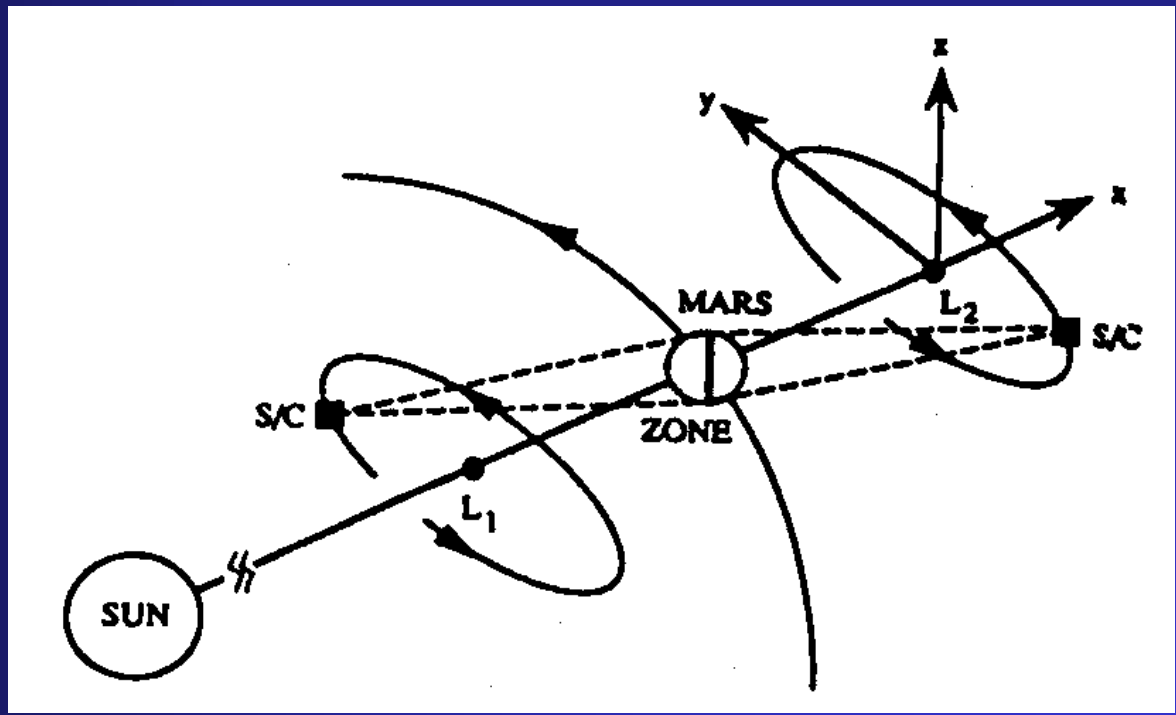
Introduction

- *"NASA is seeking innovation to attack the diversity of Mars…to change the vantage point from which we explore…"* - CNN, 25 June 2001

- Sensitivities of 2016 Earth - Mars Transfer and LOI
- Desktop Computer Simulation
- Military Graduate Research / Industry Collaboration

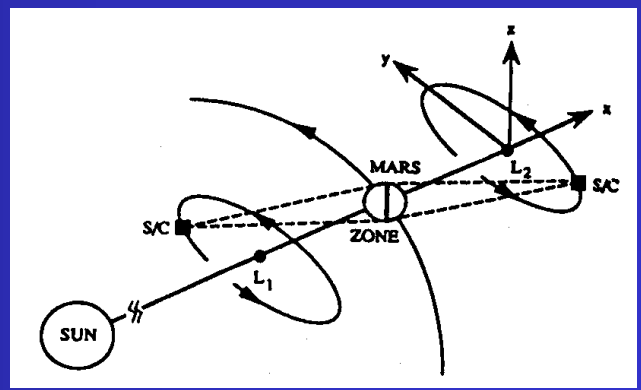
Sun-Mars Libration Point Missions





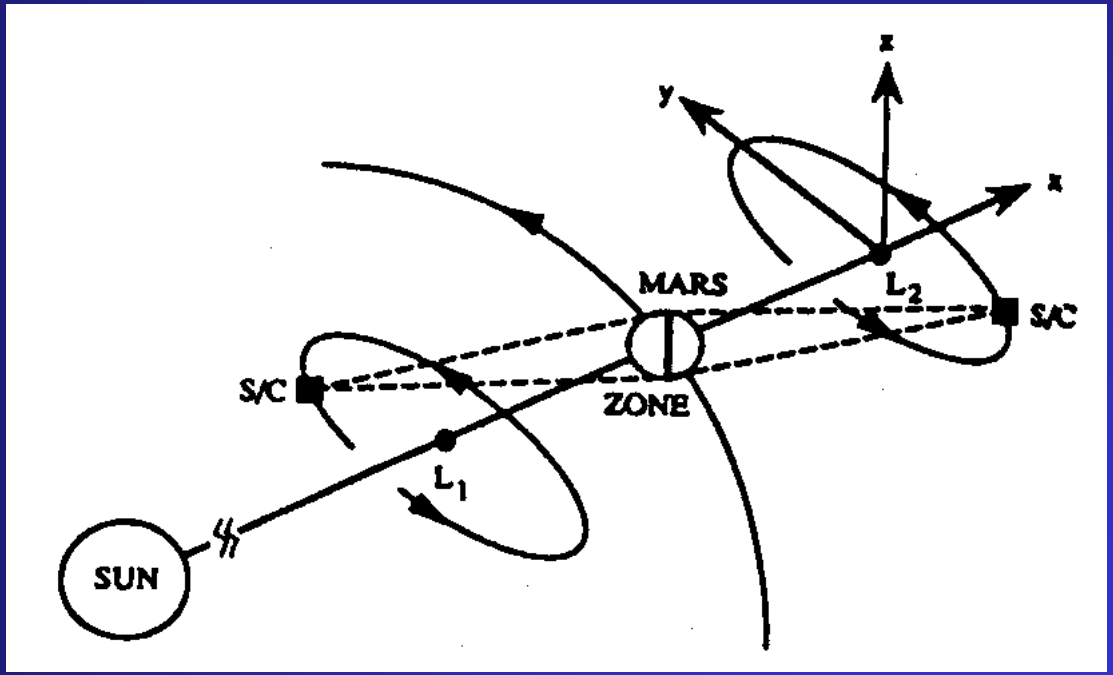
Sun-Mars Libration Point Missions

- L_1, L_2 Lagrange Points
  - 2 satellites – one in orbit about each point
  - Near-continuous coverage of Mars surface / orbit
  - Near-continuous link to Earth
- L_1, L_2 Lissajous Orbits
  - Satellites orbit around L_1, L_2 points
  - Satellites opposed 180°, same direction orbit
  - Each satellite views “half” of Mars
    - ~99% of planet at all times



Sun-Mars Libration Point Missions

- L_1, L_2 Point Mission Considerations
  - Efficient Maintenance of 180° offset
    - insertion maneuvers, stationkeeping
  - Solar Exclusion Zone
    - Period > 0.9 yrs

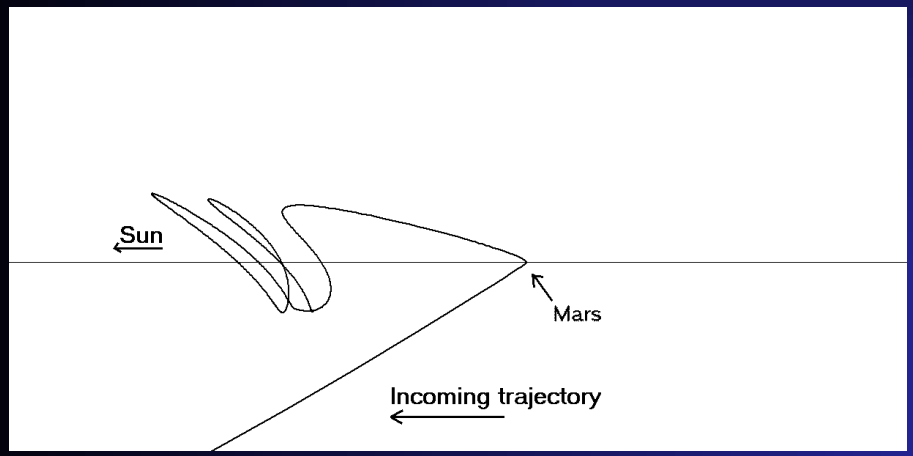


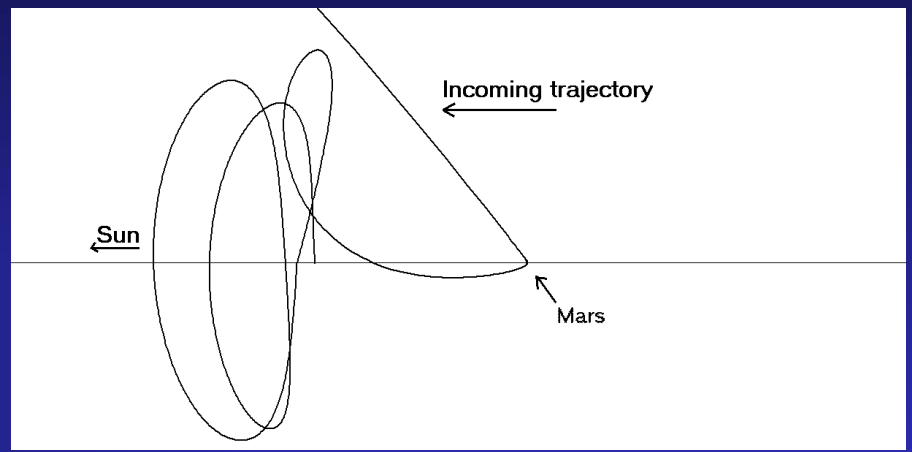
Sun-Mars Libration Point Missions

- Lissajous Orbit Constellation Advantages
  - 2 spacecraft required - minimum cost
  - L1 spacecraft can always see Sun, Earth
  - Long orbit period - simple tracking from Martian landers
  - Observation platforms
  - Small ΔV maneuvers required
- Disadvantages
  - 1 million km distance - satellite to lander
  - Solar radiation interference
  - Loss of one satellite significant

Mission Simulations and Analysis

- 2003 Transfer with Braking Maneuver

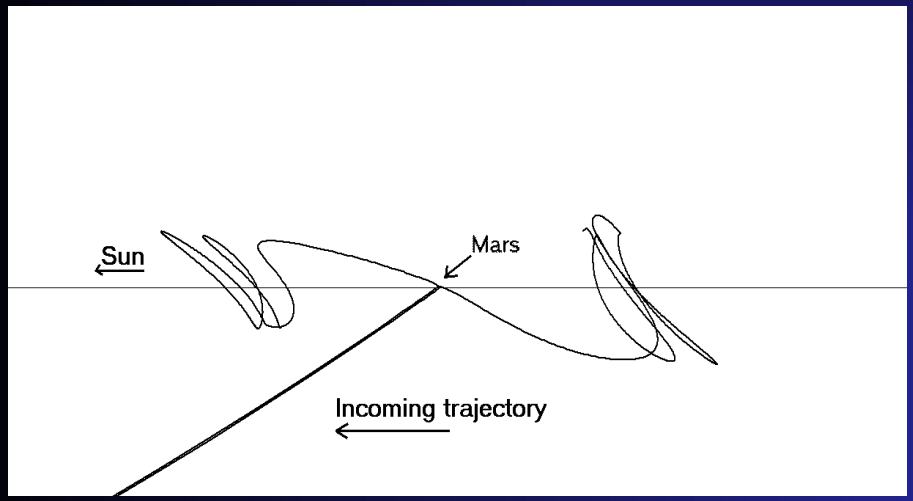


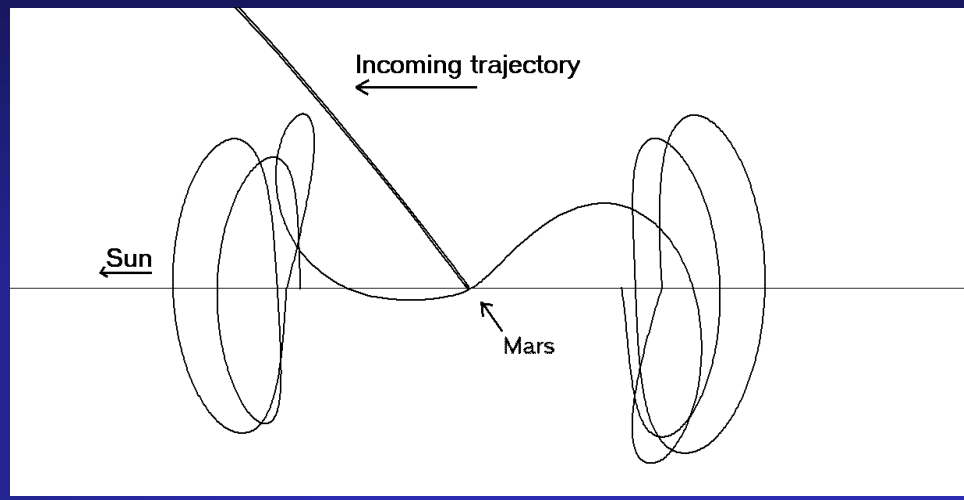


Scenario	C3 Energy (km^2/sec^2)	Braking Δv (km/sec)	Orbit Insertion Δv (km/sec)	Total Δv (km/sec)
Direct Injection	8.883	0	2.425	2.425
Braking Maneuver	9.056	0.856	0.104	0.960

Mission Simulations and Analysis

- 2016 Transfer with Braking Maneuver - Baseline





Orbit	C3 Energy (km^2/sec^2)	Mid-course Δv (km/sec)	Braking Δv (km/sec)	Orbit Insertion Δv (km/sec)	Total Δv (km/sec)
L1	10.377	0	1.710	0.047	1.757
L2	10.377	0.001	1.708	0.085	1.795

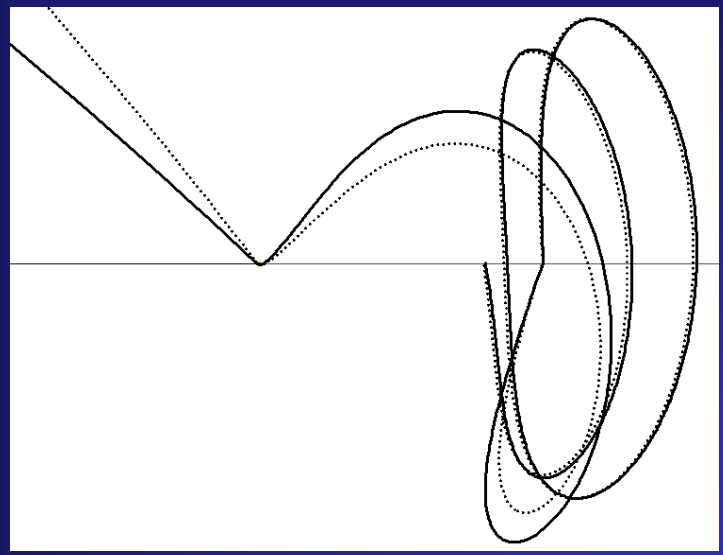
56 Day Difference Between LOI Epochs

Mission Simulations and Analysis

- Relative 180 deg Phasing Selection for S/C
- Achieve by:
  - Separate Launches
  - Relative phasing control via on-board propulsion
- Three methods to control phasing:
  - Midcourse Correction (MCC) Maneuver
  - TOF Adjustment from Mars Periapsis to LOI
  - Martian Phasing Loop

Mission Simulations and Analysis

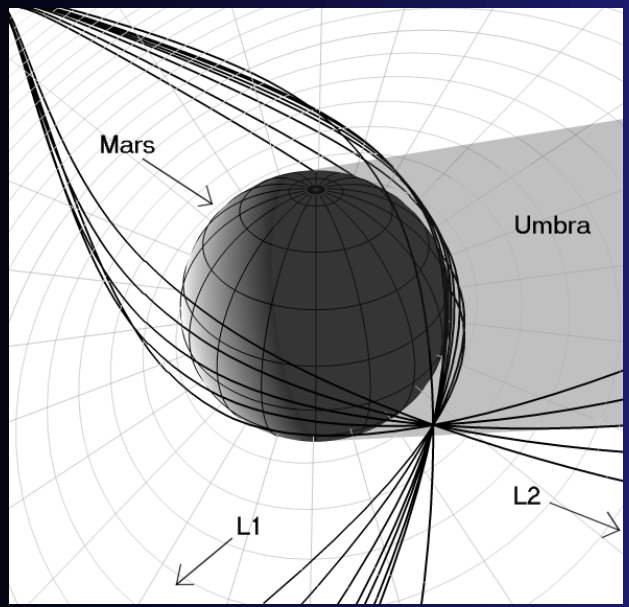
- Midcourse Correction (MCC) Maneuver
  - Change time of arrival at periapsis Mars, LOI
  - (Solid line)

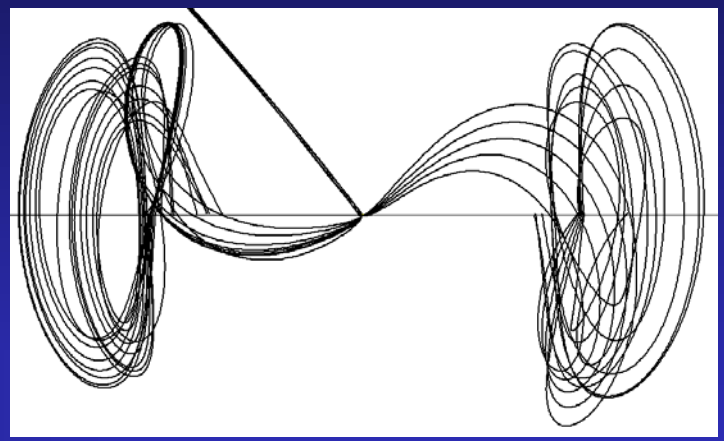


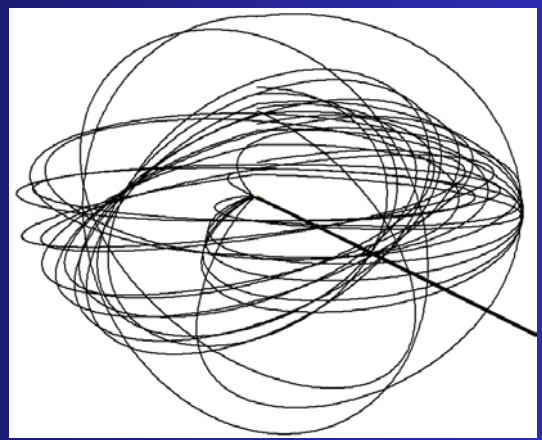
Vehicle/case	MCC Mag (km/s)	Retro ΔV (km/s)	Periapsis Date	LOI Diff. from L1 Orig. (Days)
L1 Original	0.00	1.71017	7 Sep 2016	0.00
L2 Original	0.00129	1.70843	7 Sep 2016	56.42
L2 –10 Days	0.281	2.00874	28 Aug 2016	58.62

Mission Simulations and Analysis

- TOF Adjustment from Mars Periapsis to LOI
  - B-plane correlates with Z-amplitude
  - Amplitude correlates with TOF

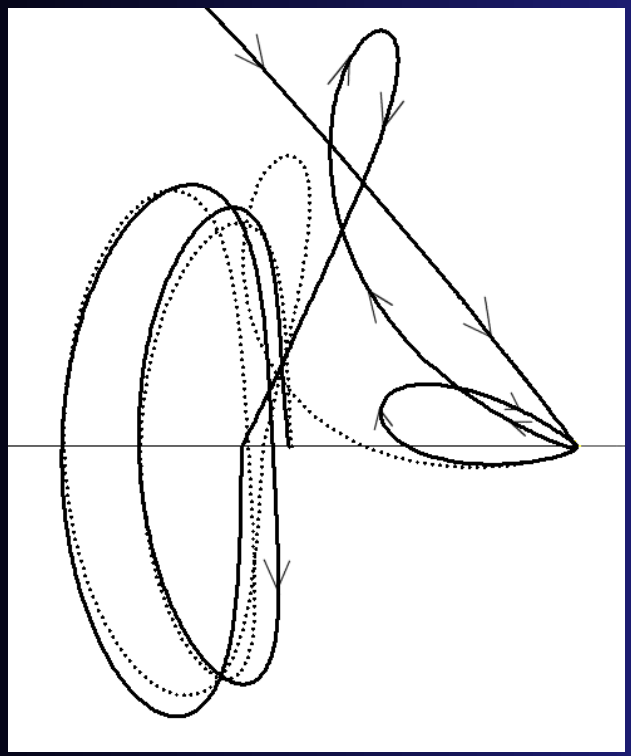


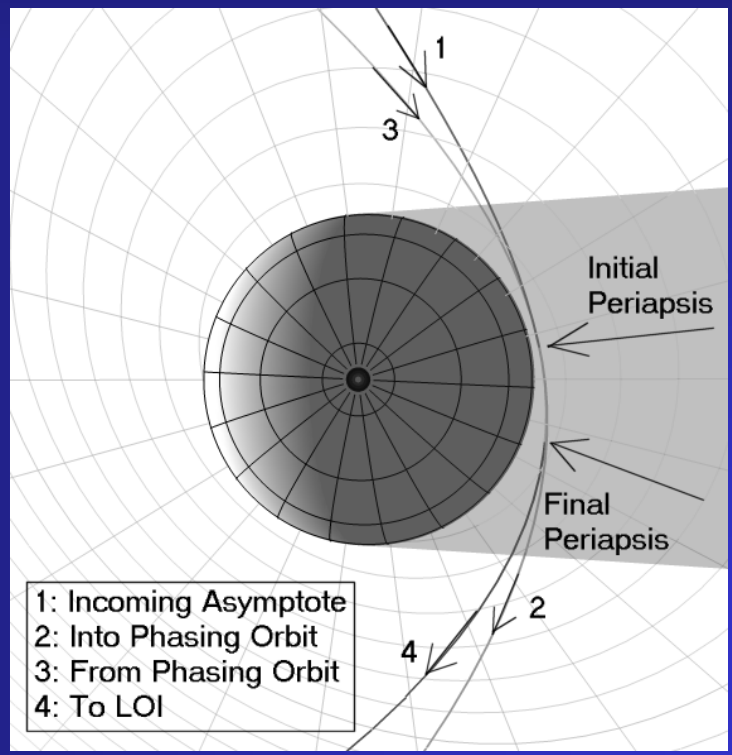




Mission Simulations and Analysis

- Martian Phasing Loop
  - Phasing orbit period < LOI epoch difference due to periapsis rotation and transfer TOF





Communication Coverage

- Use properly phased system to determine gaps
  - Max revisit time
    - duration of gap over interval
  - Start at LOI
    - propagate for 674 days
    - determine visibility
    - latitude points at one longitude

Latitude (deg)	Max Revisit Time (hrs)	Number of Gaps
90.0	0.000	1
80.0	3.639	61
70.0	5.117	335
60.0	3.499	584
50.0	1.707	902
40.0	0.696	890
30.0	0.494	846
20.0	0.441	785
10.0	0.463	733
0.0	0.486	688
-10.0	0.512	649
-20.0	0.543	609
-30.0	0.650	574
-40.0	0.845	524
-50.0	1.210	491
-60.0	5.994	436
-70.0	5.729	237
-80.0	7.425	130
-90.0	148.645	3

Targeting Methods with STK Astrogator

- Direct Transfer

Stage	Controls	Constraints	Dimension
I	C3 Targ.Vec. RA Targ.Vec. Dec	Epoch X_{RLP} Z_{RLP}	3x3

Targeting Methods with STK Astrogator

- Lissajous Orbit Insertion

Stage	Controls	Constraints	Dimension
I	ΔV_{LOIv} ΔV_{LOIn} ΔV_{LOIc}	Post LOI: Vx_{RLP} Vy_{RLP} Vz_{RLP}	3x3
II	ΔV_{LOIv}	1^{st} XZ Plane Cross: $Vx_{RLP} = 0$	1x1
III	ΔV_{LOIv}	2^{nd} XZ Plane Cross: $Vx_{RLP} = 0$	1x1
IV	ΔV_{LOIv}	3^{rd} XZ Plane Cross: $Vx_{RLP} = 0$	1x1

Targeting Methods with STK Astrogator

- Braking Maneuver

Stage	Controls	Constraints	Dimension
I	C3 Targ.Vec. RA Targ.Vec. Dec	Periapsis Epoch B·T B·R	3x3
II	C3 Targ.Vec. RA Targ.Vec. Dec	Periapsis Epoch B·R $\lvert R_p \rvert$	3x3
III	ΔV_{retro}	1^{st} XZ Plane Cross: X_{RLP}	1x1
IV - VII	Same as LOI	Same as LOI	3x3,1x1

Targeting Methods with STK Astrogator

- Z Amplitude Variations

Stage	Controls	Constraints	Dimension
I	ΔV_{MCCx} ΔV_{MCCy} ΔV_{MCCz}	Periapsis Epoch B·T B·R	3x3
II	ΔV_{MCCx} ΔV_{MCCy} ΔV_{MCCz}	Periapsis Epoch B·R $\lvert R_p \rvert$	3x3
IIa	Adjust B·R to get approximate Z_{RLP}; repeat stage II		
III	ΔV_{retro}	1^{st} XZ Plane Cross: X_{RLP}	1x1
IV	ΔV_{MCCx} ΔV_{MCCy} ΔV_{MCCz} ΔV_{retro}	Periapsis Epoch $\lvert R_p \rvert$ 1^{st} XZ Plane Cross: X_{RLP} Z_{RLP}	4x4
V - VIII	Same as LOI	Same as LOI	3x3,1x1

Phasing Loop Targeting

- Modified Target Procedure
  - After one phasing loop by L1 s/c, LOI matches L2 s/c
  - Two simultaneous differential corrector targeting schemes
- Inner Targeter
  - Transfer from phasing loop to LOI
- Outer Targeter
  - Retrograde maneuver at first Mars periapsis

Stationkeeping

- Monte Carlo Analysis
  - Uncertainties modeled as uncorrelated errors
    - 100 m in position
    - 10 cm/s in velocity
    - 10% uncertainty in area of spacecraft

    ΔV error of 10 cm/s
  - Vary these parameters; propagate L2 s/c for 90 days
  - SK maneuver to return trajectory to periodic; propagate for 1 year
  - Gather statistics for this “correction”
- 100 runs
  - Mars L2: DV = 0.044 m/s (0.003 std dev)
  - Earth L2: DV = 0.45 m/s (0.03 std dev)
  - Earth L2 (45 days): DV = 0.43 m/s (0.03)

Conclusion

- Three methods explored to control phasing
  - Use of phasing loop achieves 180 degree offset
- Communications coverage explored
  - Most latitudes experience ~30 minute gap
  - Poles experience few gaps, but longer (up to 6 days)
- Monte Carlo analysis for stationkeeping
  - Mars orbits require about order magnitude less than similar Earth orbit
  - Room for further study